Nationaal Lucht- en Ruimtevaartlaboratorium
National Aerospace Laboratory NLR

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TTCS Component Box Thermal Vacuum Test Plan

National Aerospace Laboratory (NLR)

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G. van Donk	2009-05-12
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Summary

For the AMS experiment onboard the International Space Station a thermal control system, known as the Tracker Thermal Control System (TTCS) is being developed. The TTCS basically consists of a mechanically pumped two-phase loop, where heat is collected at two evaporators and rejected at two radiators. The loop contains carbon dioxide. Critical parts of the loop are protected against freezing, using thermostats and heaters.
The various components of the TTCS are concentrated in so called primary and secondary components boxes, being part of the respective redundant primary/secondary thermal control loops.

This document describes the plan and procedure for the thermal vacuum test to be performed on a component box. The test is envisaged to be carried out in the thermal vacuum chamber of the University of Perugia (Polo scientifico Didattico di Terni, Laboratorio SERMS), in Terni – Italy.

Document change log

Doc issue	Sections	Comments	Changed by
1.0	All	Initial issue	G. van Donk
1.1	Fig 3-1 Fig 5-1 Fig 5-2 Fig 5-3 Chptr 8,9	Circular HX changed to flat Heat eXchanger Circular HX changed to flat Heat eXchanger Simplification Circular HX changed to flat Heat eXchanger Temperature cycles changed; $T_{NO,max}$ = 65 °C added Different test set-up for Primary and Secondary TTCB	G. van Donk
1.2	 9.1	Temperature sensor locations update Reference sensor description explicitly added	G. van Donk

(27 pages in total)

1 Introduction

Prior to further integration into the overall AMS, the TTCS primary and secondary component boxes will be subjected to a thermal vacuum test. During the tests the item under test will be in a vacuum <1*10^{-5} hPa (mbar) and the environmental temperature (shroud and heat sink) will be varied to maximum and minimum non-operating and operating temperatures.

Functional tests will be performed prior to, during, and after the thermal vacuum test.

2 Personnel and responsibilities

2.1 General

All tests will be performed under facility QA surveillance.

2.2 Responsibility

The technical responsibility for testing, test results reporting and test witnessing is up to a TTCS representative.

Facility personnel shall operate the TV-Chamber in order to guarantee the test temperature and pressure level requirements are met..

2.3 QA witness of test and sign-off

QA inspector, or its delegate, shall witness the tests described in this procedure.

2.4 Non conformance and failures

Any malfunction/defect which occurs during the test will be processed along the with a Non Conformance Report

2.5 Calibration

Test equipment and instrumentation used during testing shall be calibrated by its owner and shall be within validity date.

3 Item under test

The item under test consists of the Tracker Thermal Component Box (TTCB), as shown in *Figure 3-1*, and the Tracker Thermal Control Electronics (TTCE), electrically connected to the TTCB.

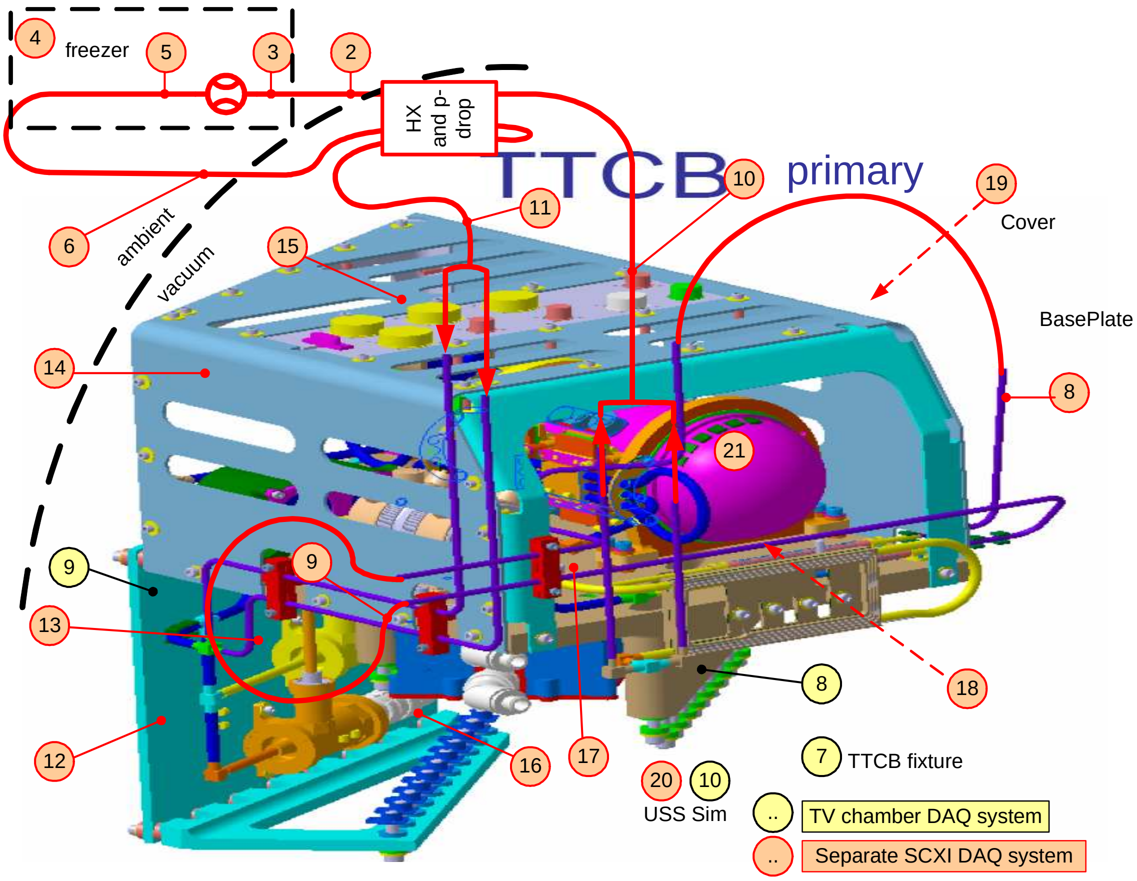


Figure 3-1: Tracker Thermal Component** primary* ***Box (here without USS simulator)

Red lines indicate temporary hydraulic connections to be made for (thermal vacuum) test purposes only.

4 Test objective

The test objective is to check the ability of the test item to withstand a thermal vacuum environment in both operational and non-operational mode.

5 Test set-up

5.1 Test set-up: schematically

The test set-up is shown schematically in *Figure 5-1*.

The TTCB and TTCE are located inside the thermal vacuum chamber. The TTCB is connected electrically to the TTCE and hydraulically to a reference liquid flow meter. As the reference flow meter cannot withstand a vacuum environment, it has to be located outside the chamber. However, as the TTCS working fluid (CO_2) caloric heat pick-up capability is low ($\dot{m} * c_p$ is low), the external flow meter and tubing have to be thermally controlled. Otherwise the CO_2 liquid leaving the chamber may vaporize during its flow outside the controlled thermal vacuum environment. Vapour entering the pumps shall be avoided not only because in the long term it may damage the pumps, but also because the TTCS normal operation is with sub-cooled liquid entering the pumps. Vapour entering the liquid flow meter will cause erratic flow readings. On top of that, a safety measure in the TTCS control prevents the pumps from running in a vapour condition, by increasing the accumulator set-point.

As with the envisaged method of using a commercial freezer outside the chamber, still heat will leak from the environment into the working fluid at the chamber feed through and part of the flow meter exit tubing, an additional simple heat exchanger is connected just at the TTCB liquid inlets. This will ensure that the working fluid is always conditioned at the required temperature.

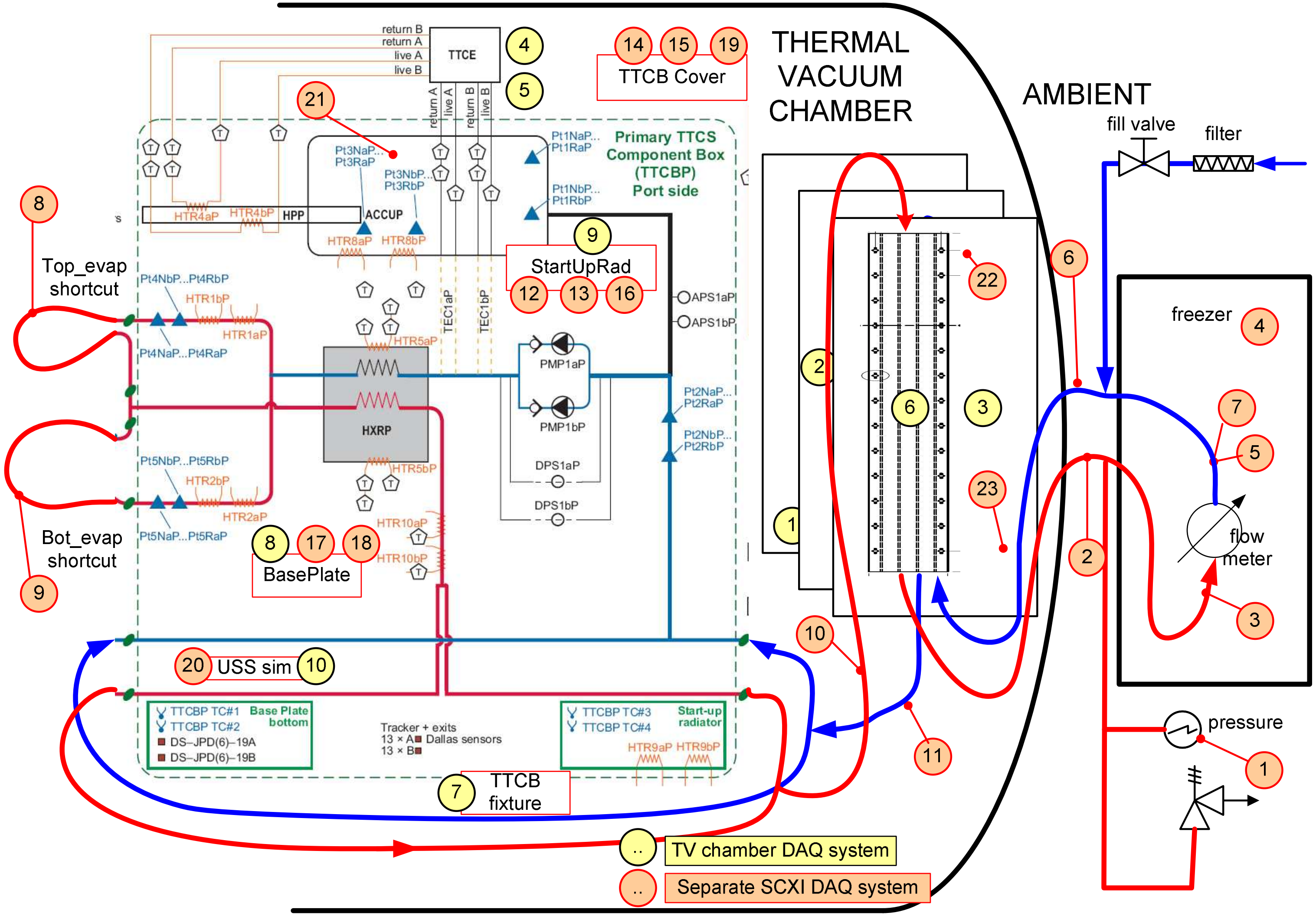


Figure 5-1: Test set-up schematic

5.2 Test set-up: physical connections

The test set-up, using the SERMS laboratory thermal vacuum chamber, is shown in *Figure 5-3* for TTCB–primary and *Figure 5-4* for TTCB-secondary. Several vacuum feed throughs are required: an electrical feed through for the TTCE and two hydraulic (6mm stainless steel tube) feed throughs, see *Figure 5-2*, are required for the TTCS working fluid (CO_2).

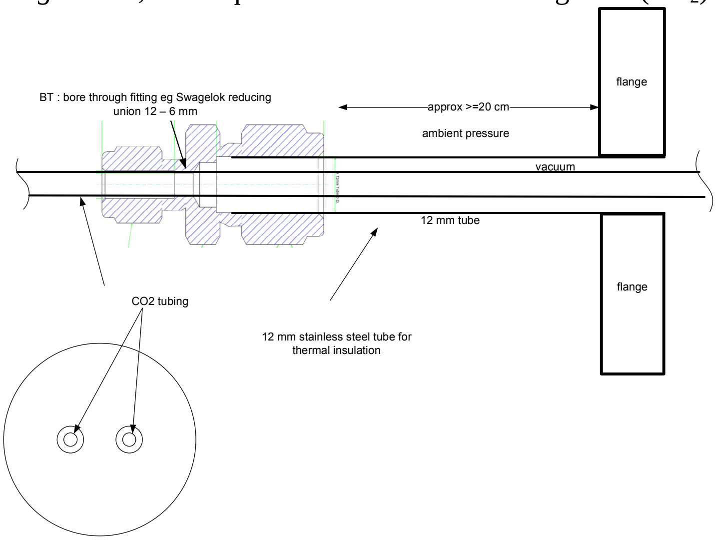


Figure 5-2: hydraulic feed through

A system to command the TTCE must be accommodated. Furthermore an additional data-acquisition system is required to gather the environmental data (shroud and cold plate temperature and pressure) as well as some working fluid temperatures and mass flow. A list of all test equipment and accessories is shown in *Table 1*.

Item	Test equipment and accessories	Responsible
1.	Thermal vacuum chamber	INFN
2.	Mass flow meter (Requirements: flowrange: 0-10 ml/s CO_2; Trange -40 to +30 °C),	NLR
3.	Representative pressure drop ‘generator’; tubing integrated with heat exchanger, incl capillary tubing (D_{out}=3mm)	NLR
4.	CO_2; quality 4.5 (99.995 vol%)	INFN
5.	Fill system	SYSU
6.	Pressure sensor	NLR
7.	Freezer to accommodate flow meter and tubing (<= -20 °C)	INFN
8.	Hydraulic vacuum feed through (6mm CO2 tubing)	INFN
9.	TTCE electrical vacuum feed through	INFN
10.	Total # of temp-sensor vacuum feed throughs =10	INFN
11.	Dry vacuum pump to evacuate the TTCB CO_2 loop	INFN
12.	Dry leak tester, to leak test the TTCB	INFN
13.	Data acquisition system (PC + LabVIEW S/W), T sensors, massflow reading (RS232), voltage	INFN
14.	Total # of test temperature sensors (vacuum + ambient)=15	INFN
15.	24 metres (in 3 metre pieces) ss316L annealed clean tubing, Dockweiler TCC.1 6,00x1,00	INFN
16.	(Swagelok) valve & fittings & appendages - Fill valve (1) - Empty valve (1) - CO_2 filter (1) - Pressure relief valve (set at 90 bar TBC) (1) - 6/3 mm reducing union (2) - 6/4 mm reducing union (8) - 6/¼ ” NPT (2) - 6 mm union T (4) - 6/¼ “ reducing union (2) - ??	NLR
17.	Cutting tools and general tools	INFN

Table 1: Test equipment and accessories

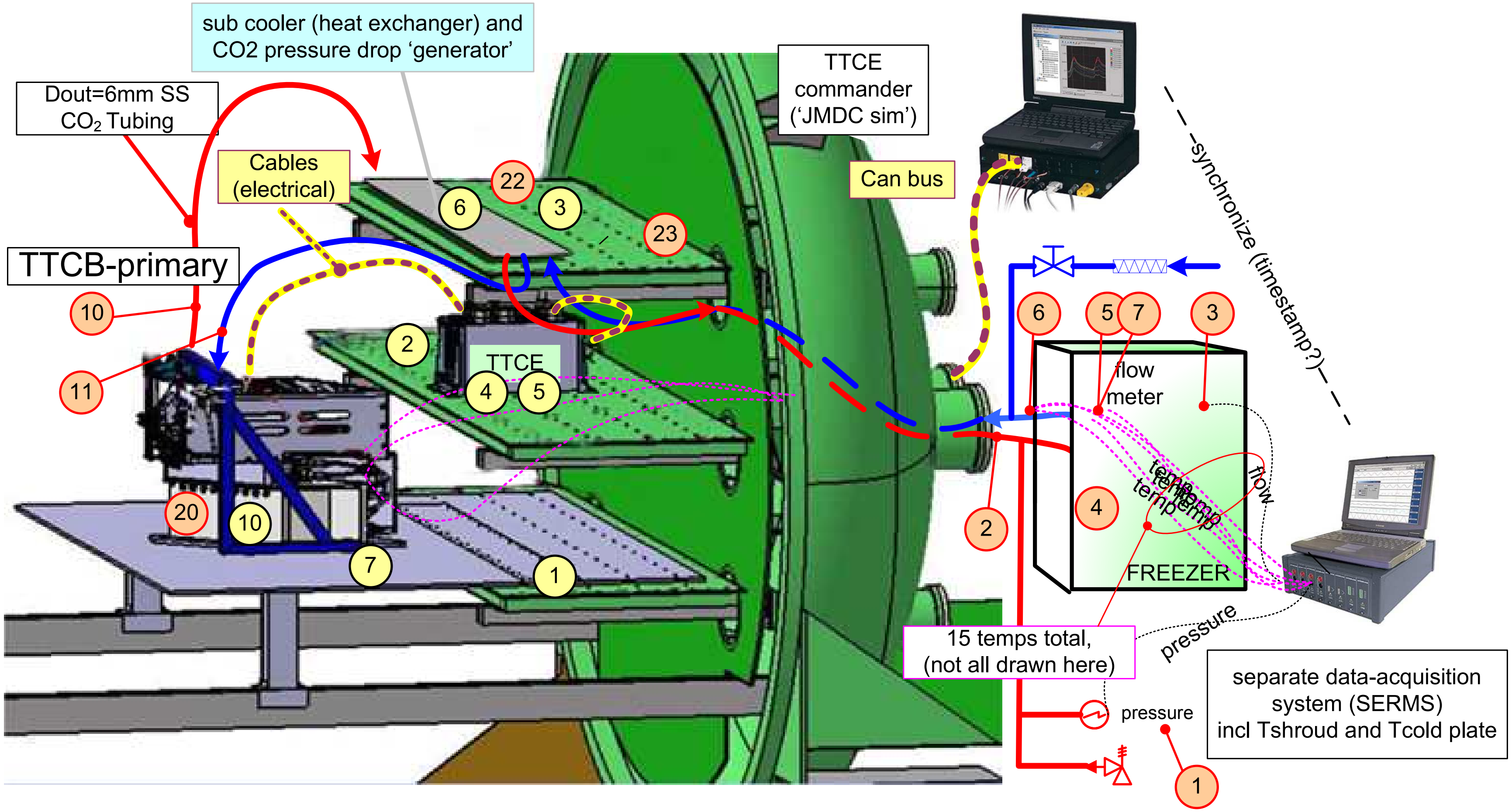


Figure 5-3: TTCB-primary Test set-up in SERMS Thermal Vacuum Chamber

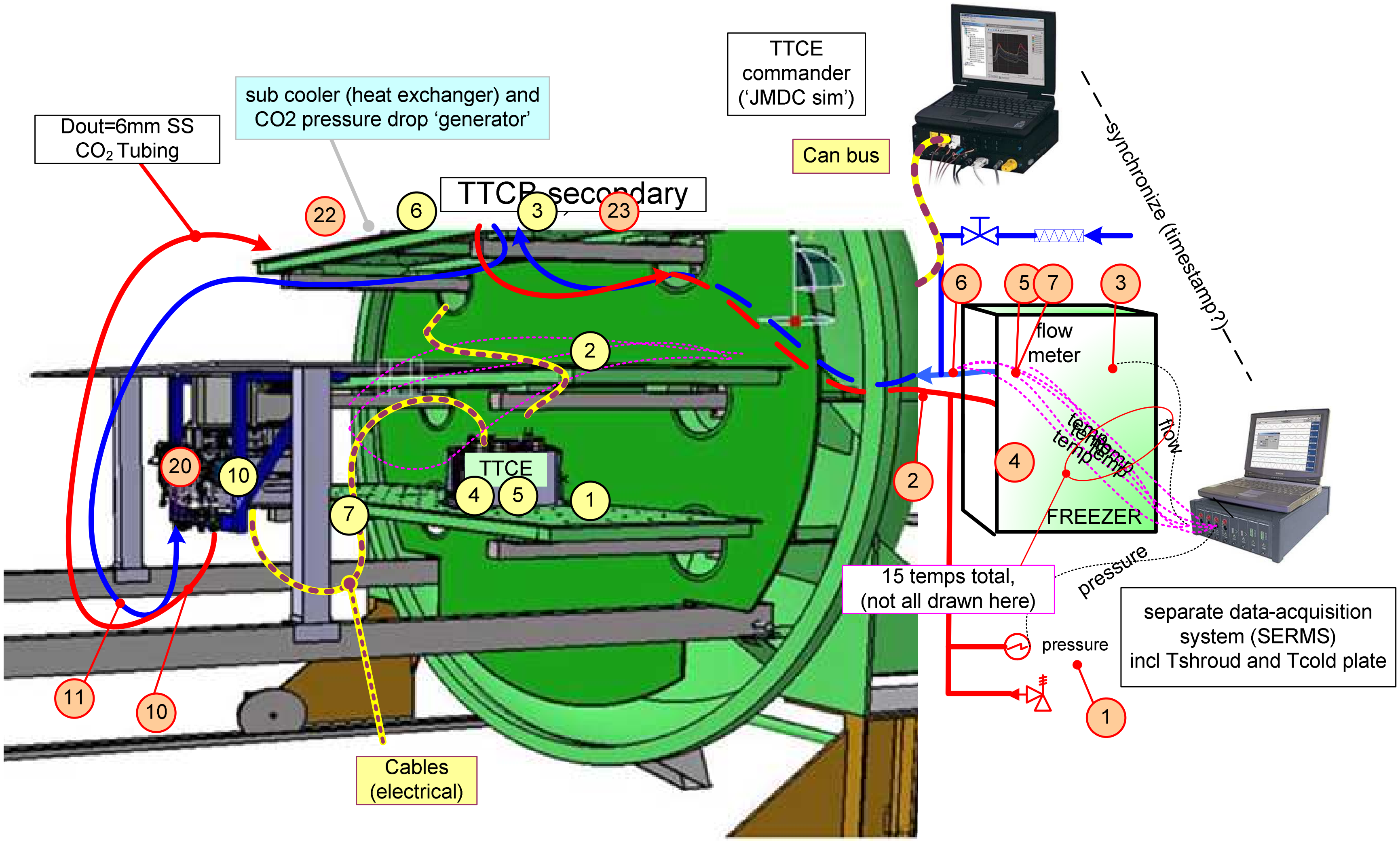


Figure 5-4: TTCB-secondary Test set-up in SERMS Thermal Vacuum Chamber

6 Test preparation

6.1 Tubing

A shortcut must be installed for the top and bottom evaporator in- and outlets. Extreme care shall be taken to avoid fouling of the tubing. The shortcut tubing and fittings shall be clean (electro polished stainless steel tubing).

The condenser return lines must be connected together and the condenser feed lines must be connected together. Both connected lines must be connected –via the pressure drop generator/heat exchanger to the flow meter outlet and flow meter inlet respectively. The pump inlet liquid will be subcooled by this external heat exchanger and the liquid leaving the TTCB will also be cooled by the external heat exchanger. The latter is required because heat will be dissipated during functional testing and vapour entering the liquid flow meter is to be avoided.

6.2 Leak tightness

After installing the tubing, leak tightness is to be checked to prevent too high working fluid losses or chamber depressurization problems. The **<u>Helium sniffer method is not allowed</u>**, as it is unclear how to remove the Helium, once it is inside the TTCB system. If He persists inside, subsequent leak tests may become problematic.

6.3 Test sensors

The proper functioning of the test item shall be checked against the following test sensors/meters:

- flow meter
- absolute pressure sensor
- various temperature sensors as shown in *Figure 3-1* and *Figure 5-1*.

The SERMS Thermal Vacuum chamber control equipment allows the user to acquire some additional signals (temperatures). These sensors are marked yellow in the figures mentioned above. A separate data-acquisition system –a National Instruments SCXI system programmed in LabVIEW and modified to fulfil the requirements for this specific test- provides additional data and the pressure and temperature sensors are marked orange in aforementioned figures.

6.4 Loop filling

If the volume was not determined in an earlier stage, the total test item volume including test tubing shall be determined by measurement. During the volume measurement the complete test set-up shall be in thermal equilibrium, prior to depressurization of the thermal vacuum chamber.. The system shall be filled such that the liquid level in the accumulator is sufficient to submerge the heat pipe during all operational tests.

6.5 Data-acquisition

Temperature sensors (e.g. Pt-100's) shall be installed at the locations, numbered according to "NLR ID", as shown in *Figure 3-1* and *Figure 5-1* and described in

SCXI data-acquisition system				
SCXI channel in data file	**Pt ID SERMS**	**NLR ID**	**Description**	**Photo**
Ch 0	1	1	Pressure	
Ch 1	2	2	Flowm_in_amb	SCXI PT 2
Ch 2	3	3	Flowm_in_frzr	SCXI PT 3
Ch 3	4	4	FreezerWall	SCXI PT 4 SCXI PT 4_2
Ch 4	5	5	Flowm_out_frzr1	SCXI PT 5
Ch 5	6	6	Flowm_out_amb	SCXI PT 6 SCXI PT 6_2
Ch 6	7	7	Flowm_out_frzr2	
Ch 16	17	8	Top_evap	SCXI PT17 SCXI PT17_2
Ch 17	18	9	Bot_evap	SCXI PT 18 SCXI PT 18_2
Ch 18	19	10	TTCB_HX_out	SCXI PT 19 SCXI PT 19_2
Ch 19	20	11	TTCB_pmp_in	SCXI PT 20 SCXI PT 20_2
Ch 20	21	12	StartUpRad1	SCXI PT 21 SCXI PT 21_2
Ch 21	22	13	StartUpRad2	SCXI PT 22 SCXI PT 22_2
Ch 22	23	14	TTCBcover1	SCXI PT 23 SCXI PT 23_2
Ch 23	24	15	TTCBcover2	SCXI PT 24 SCXI PT 24_2
Ch 24	25	16	StartUpRad3	SCXI PT 25 SCXI PT 25_2
Ch 25	26	17	TTCB_Baseplate1	SCXI PT 26 SCXI PT 26_2
Ch 26	27	18	TTCB_Baseplate2	SCXI PT 27 SCXI PT 27_2
Ch 27	28	19	TTCBcover3	SCXI PT 28 SCXI PT 28_2
Ch 28	29	20	USS simulator	SCXI PT 29 SCXI PT 29_2
Ch 29	30	21	TTCB_accumulat	SCXI PT 30 SCXI PT 30_2
Ch 30	31	22	TVC_coldplate1	SCXI PT 31 SCXI PT 31_2
Ch 31	32	23	TVC_coldplate2	SCXI PT 32

Table 3 and *Table 3*. All temperature readings and flow meter reading shall be recorded using a data-acquisition system that is synchronized with de TTCE read-outs as well as the thermal vacuum chamber housekeeping data (pressure and temperatures). Time stamp synchronisation in the data-files is sufficient. In this case computer clocks or test start time shall be synchronised.

TV Chamber sensors				
Channel on graph	**Channel on table**	**NLR ID**	**Description**	**Photo**
5	4	1	Lower Cold plate	chamber PT 5
6	5	2	Middle cold plate	chamber PT 6
7	6	3	Upper cold plate	chamber PT 7
8	7	4	TTCE I/F	chamber PT 8
9	8	5	TTCE I/F (near the heaters PT100)	chamber PT 9
10	9	6	On NLR plate (center of plate)	chamber PT 10
16	15	7	TTCB fixture	chamber PT 16
17	16	8	TTCB baseplate	chamber PT 17 chamber PT 17_2
18	17	9	TTCB start up radiator	chamber PT 18
19	18	10	USS simulator	chamber PT 19

Table 2: External temperature sensors (TV chamber DAQ system)

SCXI data-acquisition system				
SCXI channel in data file	**Pt ID SERMS**	**NLR ID**	**Description**	**Photo**
Ch 0	1	1	Pressure	
Ch 1	2	2	Flowm_in_amb	SCXI PT 2
Ch 2	3	3	Flowm_in_frzr	SCXI PT 3
Ch 3	4	4	FreezerWall	SCXI PT 4 SCXI PT 4_2
Ch 4	5	5	Flowm_out_frzr1	SCXI PT 5
Ch 5	6	6	Flowm_out_amb	SCXI PT 6 SCXI PT 6_2
Ch 6	7	7	Flowm_out_frzr2	
Ch 16	17	8	Top_evap	SCXI PT17 SCXI PT17_2
Ch 17	18	9	Bot_evap	SCXI PT 18 SCXI PT 18_2
Ch 18	19	10	TTCB_HX_out	SCXI PT 19 SCXI PT 19_2
Ch 19	20	11	TTCB_pmp_in	SCXI PT 20 SCXI PT 20_2
Ch 20	21	12	StartUpRad1	SCXI PT 21 SCXI PT 21_2
Ch 21	22	13	StartUpRad2	SCXI PT 22 SCXI PT 22_2
Ch 22	23	14	TTCBcover1	SCXI PT 23 SCXI PT 23_2
Ch 23	24	15	TTCBcover2	SCXI PT 24 SCXI PT 24_2
Ch 24	25	16	StartUpRad3	SCXI PT 25 SCXI PT 25_2
Ch 25	26	17	TTCB_Baseplate1	SCXI PT 26 SCXI PT 26_2
Ch 26	27	18	TTCB_Baseplate2	SCXI PT 27 SCXI PT 27_2
Ch 27	28	19	TTCBcover3	SCXI PT 28 SCXI PT 28_2
Ch 28	29	20	USS simulator	SCXI PT 29 SCXI PT 29_2
Ch 29	30	21	TTCB_accumulato	SCXI PT 30 SCXI PT 30_2
Ch 30	31	22	TVC_coldplate1	SCXI PT 31 SCXI PT 31_2
Ch 31	32	23	TVC_coldplate2	SCXI PT 32

Table 3: External temperature sensors (SCXI system)

7 Work to be done after testing

7.1 Emptying the loop

Care must be taken not to damage the pressure sensors when emptying the TTCB too rapidly. Furthermore, measures shall be taken to avoid damage or contamination arising from water condense. If possible, a capillary tube is to be connected to the fill valve V1 and fed through a hot water bath and connected to an additional valve V2 as shown in *Figure 7-1*. An exhaust hose or tube can be connected and vented outside the laboratory. During emptying, the TTCE and its communication terminal shall be operational to monitor the pressure sensors. The pressure in the thermal vacuum chamber shall still be very low (<=10^{-5} mbar).

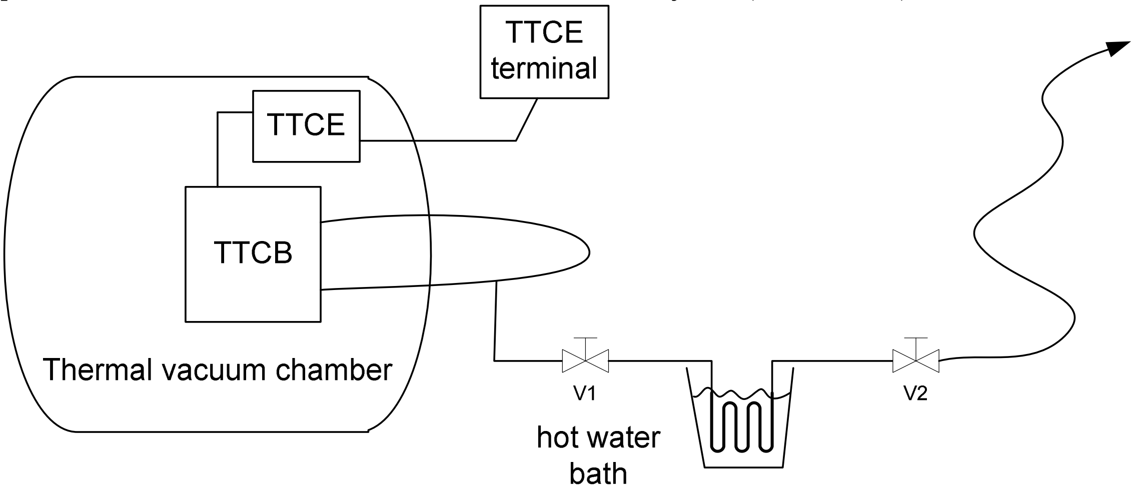


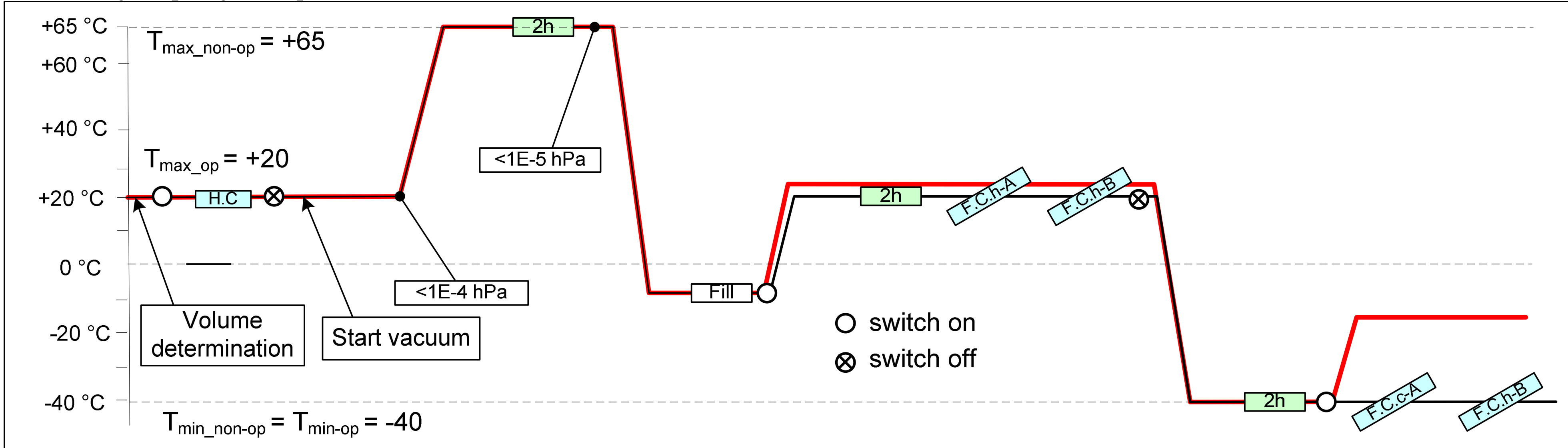
Figure 7-1: Set-up to empty the CO_2 loop

7.2 Disconnecting tubing and cables

Initial state: V1 is closed and V2 is open. Chamber is still under vacuum and the TTCE is operational. Disconnect the capillary tubing. It shall be checked that the remaining tubing is free of water condense. All temperatures (read by TTCE and additional data-acquisition system) shall be higher than the local dew point, generally > 18 °C will do. If above conditions are met, carefully open V1 until pressure is ambient. Pressurize the thermal vacuum chamber. Disconnect the TTCE terminal and cables, disconnect the flow meter and other outside appendages. Open the thermal vacuum chamber, disconnect all electrical cabling and tubing. Remove heat exchanger, TTCE and TTCB.

8 Test execution: temperature cycle

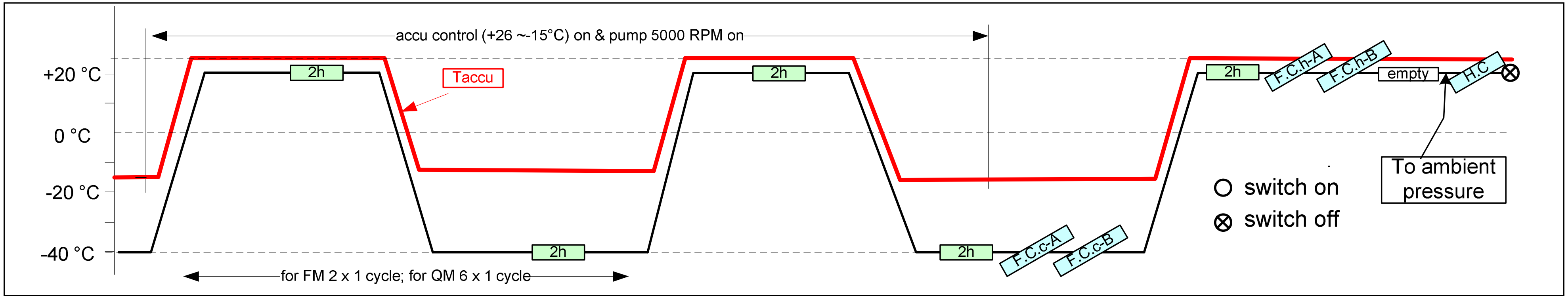
8.1 First cycle: partly non-operational



NOTE THAT DURING OPERATION THE ACCU TEMPERATURE SHALL ALWAYS BE THE HIGHEST TEMPERATURE OF THE ENTIRE CO2 LOOP

Test	Abbr	Description
Health Check	H.C	- read out all sensors - switch on heaters and verify power consumption by current change
Functional Check hot, A electronics Functional Check hot, B electronics	F.C.h-A F.C.h-B	- read out all sensors - switch on heaters (cold orbit heater excl.) and verify by T change @ 5000 RPM - set pump to 3000, 5000, 7500 & 10000 RPM (Taccu = 26°C)
Functional Check cold, A electronics Functional Check cold, B electronics	F.C.c-A F.C.c-B	- read out all sensors - switch on heaters (cold orbit heater incl.) and verify by T change @ 5000 RPM - set pump to 3000, 5000, 7500 & 10000 RPM (Taccu = -15°C)

8.2 Remaining temperature cycles (3 for FM, 7 for QM)



NOTE THAT DURING OPERATION THE ACCU TEMPERATURE SHALL ALWAYS BE THE HIGHEST TEMPERATURE OF THE ENTIRE CO2 LOOP

Test	Abbr	Description
Health Check	H.C	- read out all sensors - switch on heaters and verify power consumption by current change
Functional Check hot, A electronics Functional Check hot, B electronics	F.C.h-A F.C.h-B	- read out all sensors - switch on heaters (cold orbit heater <u>excl.</u>) and verify by T change @ 5000 RPM - set pump to 3000, 5000, 7500 & 10000 RPM (Taccu = 26°C)
Functional Check cold, A electronics Functional Check cold, B electronics	F.C.c-A F.C.c-B	- read out all sensors - switch on heaters (cold orbit heater <u>incl.</u>) and verify by T change @ 5000 RPM - set pump to 3000, 5000, 7500 & 10000 RPM (Taccu = -15°C)

9 Test execution

9.1 Reference sensors

Two reference temperatures are defined:

1) The TV chamber top cold plate temperature (sensors with NLR-ID 22 and 23), which shall be set to the required level as indicated in the procedure sheets.
2) The TTCB base plate temperature (sensors with NLR-ID 17 and 18), which shall be used for the stabilization criterion: dT/dt < 1°C/h as indicated in the procedure sheets.

9.2 Procedure sheets

These procedure sheets are intended to be used by the thermal vacuum chamber operator. Test item operation and functional checks are to be performed according to a separate detailed procedure.

	Tracker Thermal Control Box Thermal vacuum Test		company:		date:	
	Fill in by hand.		engineer:		location:	
Step	Action	Monitoring	Value	**Result**	Comment	√
1.	***** **Test item ID** *****					
2.	Record Test Item description.	T.I. description	-			
3.	Record model (EM / QM / FM)	model	-			
4.	Record test equipment used, use Table 4		-			
5.	***** **Test item installation & Health Check** *****					
6.	Install item under test as per *Figure 5-3* in the thermal vacuum chamber including all required temperature sensors, flow meter read out connection, TTCE electrical wiring		-			

Step	Action	Monitoring	Value	Result	Comment	√
	Tracker Thermal Control Box Thermal vacuum Test		company:		date:	
	Fill in by hand.		engineer:		location:	
Step	Action	Monitoring	Value	**Result**	Comment	√
7.	Check leak tightness (apart from possible other formal He leak testing; the purpose here is to prevent excessive CO_2 loss in the vacuum chamber during testing)					
8.	Wait for volume to be determined	Separate proc.				
9.	Switch on and run data-acquisition PC					
10.	Wait for TTCE and TTCE-commander to be switched on					
11.	Wait for Health Check (Vacuum chamber is still open)	Separate proc.				
12.	Wait for TTCE to be switched off					
13.	******* Chamber depressurization *******					
14.	Close the thermal vacuum chamber					
15.	Depressurize chamber and wait until required pressure level is reached	p_chamber	<1E-4 hPa			
16.	Increase shroud and cold plate temperature to T_{NO_max}	Tshroud Tcold plate 22,23	$+65^{-0/+3}$ °C $+65^{-0/+3}$ °C			
17.	Wait for test item temperature stabilization	dT/dt of 17,18	<1°C/h			
18.	(After stabilization in previous step) Dwell 2 hours	Dwell time	>=2hrs			
19.	******* System filling with CO_2*******					
20.	Wait until required pressure level is reached	p_chamber	<1E-5 hPa			

	Tracker Thermal Control Box Thermal vacuum Test		company:		date:	
	Fill in by hand.		engineer:		location:	
Step	Action	Monitoring	Value	**Result**	Comment	√
21.	Decrease shroud and cold plate temperature to T_{fill}	Tshroud Tcold plate	$-10^{\pm10}$ °C $-10^{\pm10}$ °C			
22.	Wait for test item to be filled	Separate proc.				
23.	Wait for TTCE and TTCE commander to be switched on					
24.	Wait for accu temperature to rise	Taccu	Tshroud +6°C			
25.	Increase chamber shroud and cold plate temperatures, rate-of-change <= 10 °C/min.	Tshroud Tcold plate 22,23	$+ 20^{-0/+1}$ °C $+ 20^{-0/+1}$ °C			
26.	Wait for test item temperature stabilization	dT/dt of 17,18	<1°C/h			
27.	Wait dwell time	Dwell time	>= 2 hrs			
28.	Wait for Functional Check Hot, A to be performed	Separate proc.				
29.	Wait for Functional Check Hot, B to be performed	Separate proc.				
30.	Wait for TTCE to be switched off	TTCE	off			
31.	Decrease shroud and cold plate temperatures to T_{NO_min}	Tshroud Tcold plate 22,23	$-40^{+0/-3}$ °C $-40^{+0/-3}$ °C			
32.	Wait for test item temperature stabilization	dT/dt of 17,18	<1°C/h			
33.	Wait dwell time	Dwell time	>= 2 hrs			
34.	Wait for TTCE to be switched on	TTCE	On			
35.	Wait for accu temperature to be increased, (Temp stabilization not req'd)	Taccu	$-15^{\pm1}$ °C			

	Tracker Thermal Control Box Thermal vacuum Test		company:		date:	
	Fill in by hand.		engineer:		location:	
Step	Action	Monitoring	Value	**Result**	Comment	√
36.	Wait for Functional Check Cold, A to be performed	Separate proc.				
37.	Wait for Functional Check Cold, B to be performed	Separate proc.				
38.	Wait for pump to run					
39.	Increase chamber shroud and cold plate temperatures, however check that these temperatures are always at least 5 °C below accu temperature. Set rate-of-change	Tshroud Tcold plate 22,23 dT/dt	$+20^{+1/-3}$ °C $+20^{+1/-3}$ °C <1°C/min			
40.	Wait for test item temperature stabilization	dT/dt of 17,18	<1°C/h			
41.	Wait dwell time	Dwell time	>=2 h			
42.	Decrease chamber shroud and cold plate temperatures. Set rate-of-change. Verify that Taccu is always the highest temperature in the system.	Tshroud Tcold plate 22,23 dT/dt	$-40^{+0/-3}$ °C $-40^{+0/-3}$ °C <10°C/min			
43.	Wait for test item temperature stabilization	dT/dt of 17,18	<1°C/h			
44.	Wait dwell time	Dwell time	>= 2 hrs			
45.	Increase chamber shroud and cold plate temperatures, however verify that these temperatures are always at least 5 °C below accu temperature. Set rate-of-change	Tshroud Tcold plate 22,23 dT/dt	$+20^{+1/-3}$ °C $+20^{+1/-3}$ °C <1°C/min			
46.	Wait for test item temperature stabilization	dT/dt of 17,18	<1°C/h			
47.	Wait dwell time	Dwell time	>=2 h			
48.	Decrease chamber shroud and cold plate temperatures. Set rate-of-change. Verify that Taccu is always the highest temperature in the	Tshroud Tcold plate 22,23	$-40^{+0/-3}$ °C $-40^{+0/-3}$ °C			

	Tracker Thermal Control Box Thermal vacuum Test		company:		date:	
	Fill in by hand.		engineer:		location:	
Step	Action	Monitoring	Value	**Result**	Comment	√
	system.	dT/dt	<10°C/min			
49.	Wait for test item temperature stabilization	dT/dt of 17,18	<1°C/h			
50.	Wait dwell time	Dwell time	>= 2 hrs			
51.	*FOR **QM** ONLY: Perform **<u>additional</u>** 4 cycles for QM equal to the last steps described above*	*QM*	*4 cycles*			
52.	Increase chamber shroud and cold plate temperatures, however verify that these temperatures are always at least 5 °C below accu temperature. Set rate-of-change	Tshroud Tcold plate 22,23 dT/dt	$+20^{+1/-3}$ °C $+20^{+1/-3}$ °C <1°C/min			
53.	Wait for test item temperature stabilization	dT/dt of 17,18	<1°C/h			
54.	Wait dwell time	Dwell time	>=2 h			
55.	Decrease chamber shroud and cold plate temperatures. Set rate-of-change. Verify that Taccu is always the highest temperature in the system.	Tshroud Tcold plate 22,23 dT/dt	$-40^{+0/-3}$ °C $-40^{+0/-3}$ °C <10°C/min			
56.	Wait for test item temperature stabilization	dT/dt of 17,18	<1°C/h			
57.	Wait dwell time	Dwell time	>= 2 hrs			
58.	Wait for Functional Check Hot, A to be performed	F.C.h-A				
59.	Wait for Functional Check Hot, B to be performed	F.C.h-B				
60.	Increase chamber shroud and cold plate temperatures, however verify that these temperatures are always at least 5 °C below accu temperature. Set rate-of-change	Tshroud Tcold plate 22,23 dT/dt	$+20^{+1/-3}$ °C $+20^{+1/-3}$ °C <1°C/min			
61.	Wait for test item temperature stabilization	dT/dt of 17,18	<1°C/h			

	Tracker Thermal Control Box Thermal vacuum Test		company:		date:	
	Fill in by hand.		engineer:		location:	
Step	Action	Monitoring	Value	**Result**	Comment	√
62.	Wait dwell time	Dwell time	>=2 h			
63.	Wait for Functional Check Hot, A to be performed	F.C.h-A				
64.	Wait for Functional Check Hot, B to be performed	F.C.h-B				
65.	******* Follow next steps to **Empty the loop** *******					
66.	Wait for test item and loop to be empty					
67.	Wait for all test item and loop temperatures to be at required level	All temps	>19 °C			
68.	***** **Chamber pressurization** *****					
69.	Pressurize chamber	p_chamber	ambient			
70.	Wait for Health Check to be performed	Separate proc.				
71.	Wait for TTCE to be switched off	TTCE	off			
72.	Wait for TTCE commander to be switched off	TTCE commander	off			
73.	Switch data-acquisition PC off	DAQ PC	off			
74.	Disconnect all electrical wiring					
75.	Disconnect test tubing					
76.	Remove test item from chamber					
77.	***** **End of procedure** *****					

N.	Equipment	Type/manufacturer	S/N	Calibration date	Calibration due date	remarks
	TV chamber	Angelantoni				
	Chamber vacuum sensor					
	Flow meter					
	Pt-100					
	Pressure sensor					
	..					
	..					

Table 4: Equipment used